Analysis, Integration and Modeling of the Earth System

Global Research Network of Future Earth

Hannah Liddy
ESA Co-location Meeting
7 October 2021

Introduction to the AIMES

1993 - 2004
IGBP: Global Analysis, Integration and Modelling (GAIM) Task Force

Advance understanding of the coupled dynamics of the Earth System using data and models

2005
IGBP: GAIM -> Analysis, Integration and Modeling of the Earth System (AIMES)

Integrate human activity with biogeophysical Earth system analyses

2015
IGBP -> Future Earth
Science for a Sustainable Future

2017
*International Project Office Support at NASA Goddard Institute for Space Studies/Columbia University*

1990   2000   2010   2020

Ocean Carbon Cycle Model Intercomparison Project (OCMIP)

Coupled Carbon Climate Model Intercomparison Project (C4MIP)

First International Land Model Benchmarking (ILAMB) Workshop in the U.S.

GAIM TransCom2 Atmospheric Tracer Transport Model Intercomparison Project

Inverse Modeling
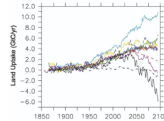
AGCI Workshop: A Strategy for Climate Change Stabilization Experiments with AOGCMs and ESMs

International Land Model Benchmarking (ILAMB) Meeting
The Beckman Center, Irvine, CA, USA January 24-26, 2011

Establishment of Working Groups:
► Modeling Earth System and Human interactions (MESH)
► Large Scale Behavioral Models of Land Use Change
► Land Data Assimilation WG
► Open Modeling Foundation

Schimel et al., 2015

W: https://aimesproject.org   T: @AIMES_IPO   *Sponsors:* futurearth   NASA   *Partners:* WCRP World Climate Research Programme   YESS community YOUNG EARTH SYSTEM SCIENTISTS community

Scientific Steering Committee

Apply to join the AIMES SSC!
https://aimesproject.org/ssc_call_2021/
Deadline: 1 November

Victor Brovkin, Mark Rounsevell, Hannah Liddy, Lisa Alexander, Govindasamy Bala, Michael Barton, Zhangang Han, David Lapola, Natasha MacBean, Brian O'Neill, Patricia Pinho, Julia Pongratz, Alex Ruane

Co-chairs: Victor Brovkin & Mark Rounsevell International Project Officer: Hannah Liddy

AIMES AND ESA CCI/CMUG OPPORTUNITIES

- **Earth system dynamics and analysis of abrupt change in models**
- Model improvement and uncertainty reduction using data assimilation
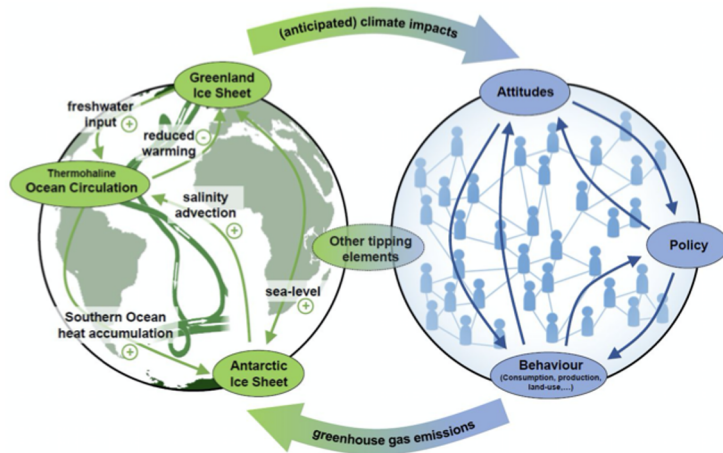- Scenario design and human-Earth system feedbacks

Tipping Points in the Earth's Climate

Forum at ISSI, Bern, 26-29 January 2021
With Future Earth AIMES project

Objective: to clarify necessary **satellite data requirements** to monitor the climate system's resilience to **tipping points**, constrain models and build on the ESA CCI programme as a foundation for a future abrupt change **early warning system**

- Ocean / Atmosphere
- Cryosphere
- Biosphere

Arctic sea ice
Greenland ice sheet
Permafrost
Boreal forest
Stratocumulus clouds
AMOC
West Africa Monsoon
Indian Monsoon
ENSO
Amazon rainforest
Coral reefs
West Antarctic ice sheet
Methane Hydrates
East Antarctic ice sheet

www.issibern.ch/forum/tippingpoints/

Tipping Elements in the Earth System

Fig. 1: Tipping elements in the Earth system and their interactions
(Source: Wiedermann, Winkelmann, Donges et al., arXiv:1911.10063
[physics.soc-ph]).

➤ Create an international science platform for the study of climatic, ecological and social tipping elements and their interactions in the Earth system.
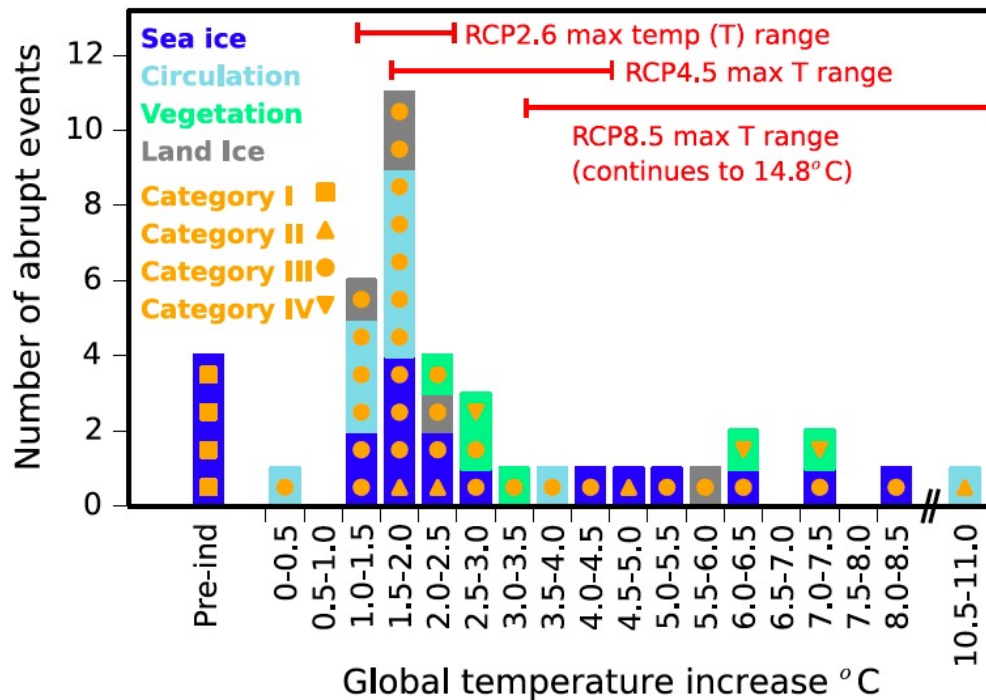
Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models

Sybren Drijfhout[a,b,1], Sebastian Bathiany[c,d], Claudie Beaulieu[b], Victor Brovkin[d], Martin Claussen[d,e], Chris Huntingford[f], Marten Scheffer[c], Giovanni Sgubin[g], and Didier Swingedouw[h]

Many abrupt changes in CMIP5 models are in the 1-3°C range

Earth System Tipping Point
Model Intercomparison Project (TIP-MIP)

➤ **Objective: Assess critical temperature thresholds for tipping elements in the Earth system, and feedbacks from tipping element shifts on the climate system**

❖ Idealized experiments; tipping elements; stand-alone models or ESMs; climate and land-use forcing

Three major sets of experiments are under discussion:

- *Experiment 1: Baseline* - climate and land-use change (climate-change only where not applicable), until 2500 / equilibrium (come-as-you-are approach)
- *Experiment 2: Commitment* - branch off at given times (e.g., 2030, 2050, 2100) to assess committed impacts
- *Experiment 3: Reversibility* - reverse forcing to assess hysteresis behaviour, in particular with respect to temperature overshoot scenarios

Tipping Elements, Irreversibility, and Abrupt Change in the Earth System
Discussion Series

20 September 2021, 12:00 - 13:30 CEST

Discussion Series: Tipping Elements, Irreversibility, and Abrupt Change of the Earth System

Date	Tipping Element	Speakers
20 September	Introduction	Tim Lenton (University of Exeter) Sonia Seneviratne (ETH Zurich)
TBD October	Cryosphere	Ricarda Winkelmann (PIK) TBD
29 November	Amazon Forest	Carlos Nobre (University of São Paulo) Peter Cox (University of Exeter
TBD December	Permafrost regions	Hanne Christiansen (UNIS) TBD

To register for upcoming events, sign up for the AIMES newsletter or bookmark this page ->

AIMES AND ESA CCI/CMUG OPPORTUNITIES

- Earth system dynamics and analysis of abrupt change in models
- **Model improvement and uncertainty reduction using data assimilation**
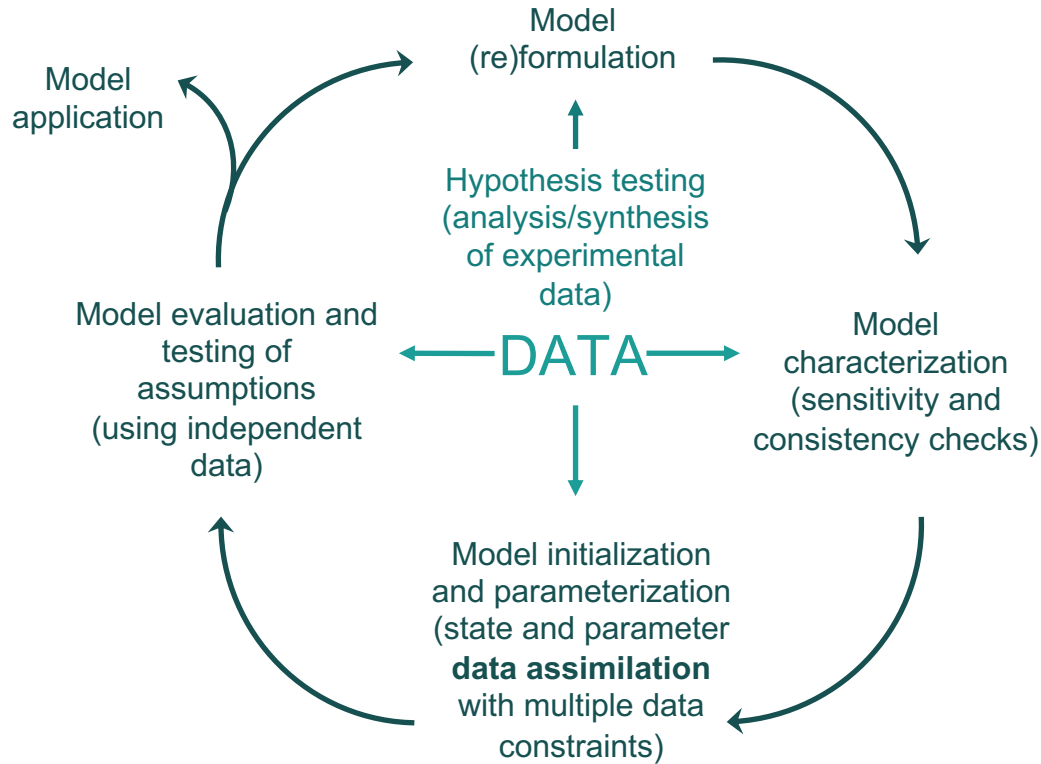- Scenario design and human-Earth system feedbacks

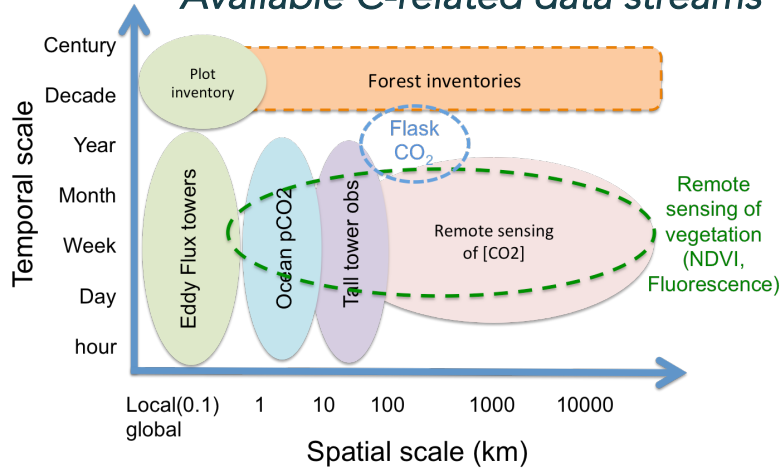# Land Data Assimilation Working Group

Steering Committee: Andy Fox (Joint Center for Satellite Data Assimilation, USA), Jana Kolassa (NASA GSFC, USA), Natasha MacBean (Indiana University, USA), Tristan Quaife (University of Reading, UK)

Model development cycle – data opportunities

Model
(re)formulation

Model
application

Hypothesis testing
(analysis/synthesis
of experimental
data)

Model evaluation and
testing of
assumptions
(using independent
data)

DATA

Model
characterization
(sensitivity and
consistency checks)

Model initialization
and parameterization
(state and parameter
data assimilation
with multiple data
constraints)

Adapted from Williams et al. (2009)

Reducing uncertainty: the need for model – data assimilation

Available C-related data streams

Temporal scale: Century, Decade, Year, Month, Week, Day, hour

Plot inventory

Forest inventories

Flask CO$_2$

Eddy Flux towers

Ocean pCO2

Tall tower obs

Remote sensing of [CO2]

Remote sensing of vegetation (NDVI, Fluorescence)

Spatial scale (km): Local(0.1) global, 1, 10, 100, 1000, 10000

Land net CO$_2$ flux (PgCyr^{-1}): -8, -6, -4, -2, 0, 2, 4, 6, 8, 10

1860 1900 1940 1980 2020 2060 2100

DATA ASSIMILATION

Bayesian data assimilation:
reduction of a "cost function" describing the misfit between the observations and the model – taking account i) uncertainty on both; ii) prior information about the model
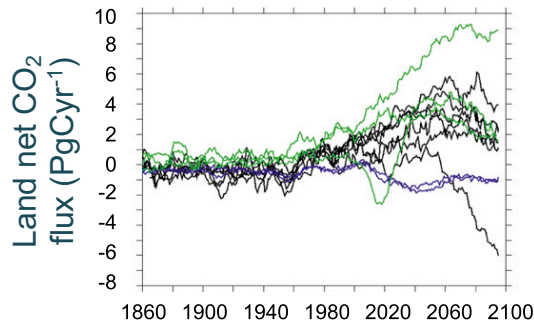
Improve:
- *C land budget estimates*
- *Quantify uncertainty*
- *Future climate predictions*
- *Process understanding*

Slide credit: Natasha MacBean

Tackling Technical Challenges in Land Data Assimilation
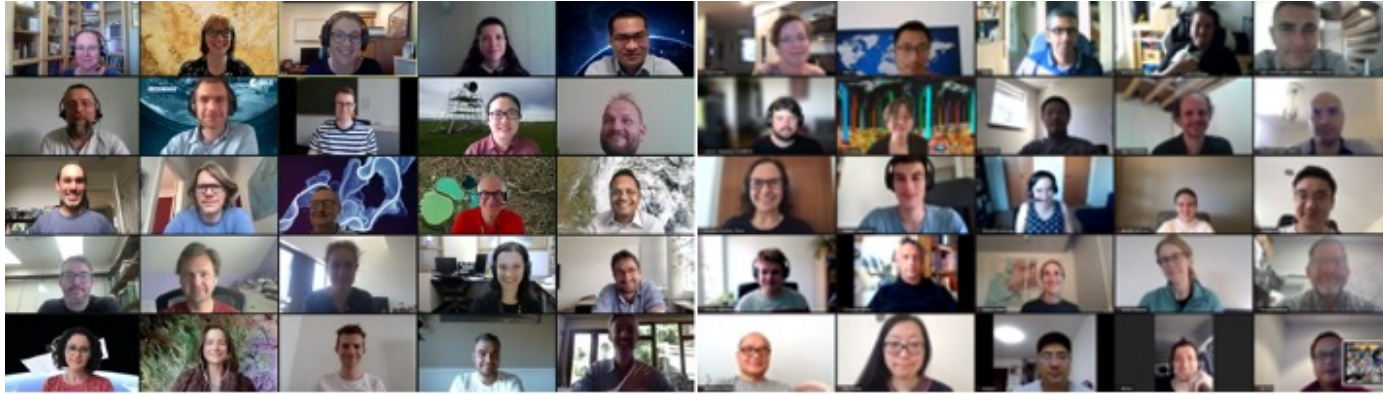
Kick-off workshop: 14-16 June with 155 scientists from 16 different countries with expertise or interest in land surface modeling and data assimilation.

Themes:
1) Applicability of DA approaches across different land modeling groups
2) Emerging techniques in DA
3) Challenges in dealing with observations

-> Watch videos on AIMES YouTube Channel: www.aimesproject.org/lda_workshop

Next steps for building the Land DA Community

- New activities planned around (1) land management (2) AI/machine learning techniques
- Data provider workshop early spring
- Sign up for land DA listserv: www.aimesproject.org/ldawg

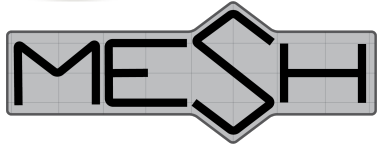*Sign up for the Land DA listserv on the AIMES website or using this QR code ->*

AIMES AND ESA CCI/CMUG OPPORTUNITIES

- Model improvement and uncertainty reduction using data assimilation
- Earth system dynamics and analysis of abrupt change in models
- **Scenario design and human-Earth system feedbacks**

Modeling the Earth System and Human interactions (MESH)

Steering Committee: Kate Calvin (PNNL, USA), Brian O'Neill (PNNL, USA), Julia Pongratz (University of Munich, MPI-M, Germany), Ben Sanderson (CNRS, France), Detlef van Vuuren (University of Utrecht, Netherlands)
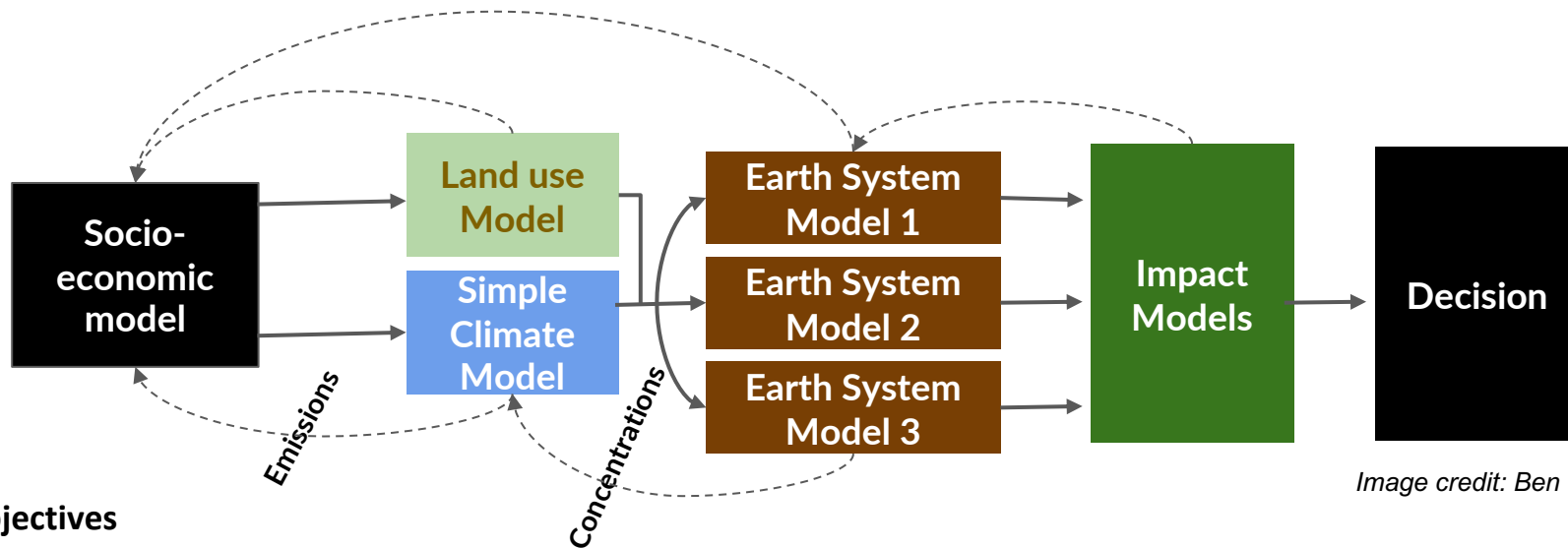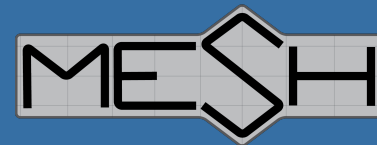
Image credit: Ben Sanderson

Objectives

1. Evaluate and quantify bidirectional feedbacks between human and Earth systems.
2. Assess methods of coupling human and Earth system models at a global scale.
3. Assess the role of coupled human and Earth system modeling within research and in future climate assessments.

Aspen C4MIP proposal for IPCC AR5 (2006): prescribe concentrations instead of emissions
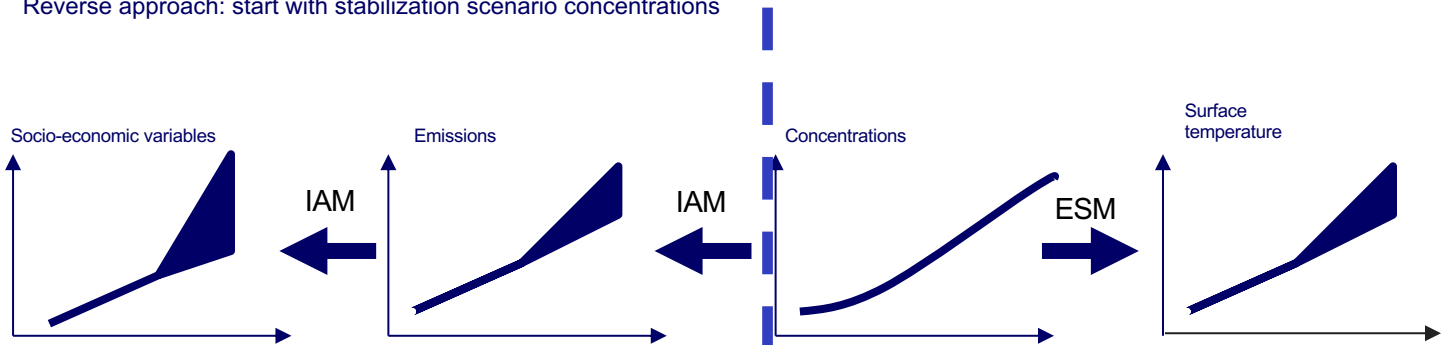
Forward approach: start with socio-economic variables
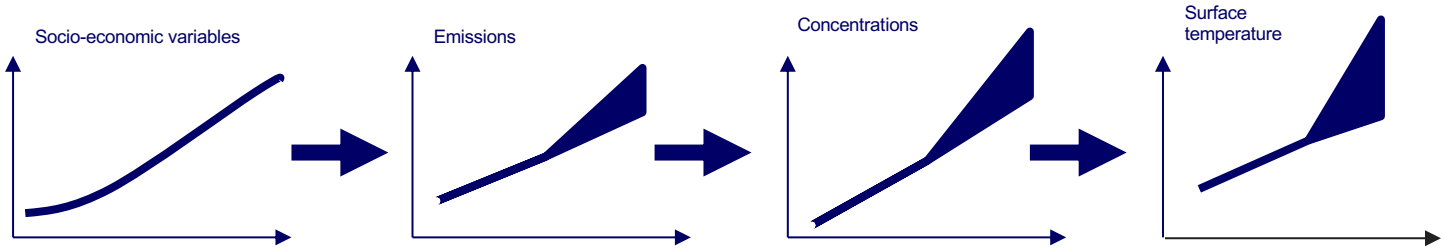
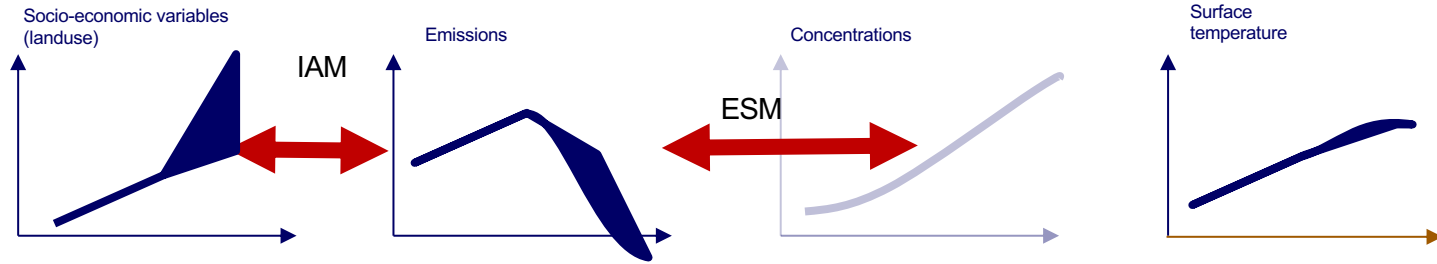Reverse approach: start with stabilization scenario concentrations

Hibbard et al., EOS, 2007

Aspen AIMES discussion (2021):
Interactions between ESMs and IAMs with feedback control

AR7?
Adaptive
control of
emissions in
ESMs,
landuse and
economy
controls in
IAMs

ZECMIP (MacDougal et al., BG, 2020): when CO_2 emissions stop, the temperature stabilizes.
A way to control temperature by emissions in ESMs (adaptive scenarios)

Summary

- Relevant working groups:

  - AIMES Tipping Elements in the Earth System

    - Register for webinar series to get involved

  - AIMES Land Data Assimilation Working Group

    - Sign up for the listserv to stay up to date and get involved in future activities

- Apply to be on the AIMES SSC! (Deadline 1 November)

  Thank you for your attention!

We thank our:

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Partners

Get Involved: Visit our website: www.aimesproject.org to join, follow us @AIMES_IPO, or email aimes@futureearth.org

AIMES Working Groups

➤ Modeling Earth System and Human interactions (MESH)

Evaluate and quantify bidirectional feedbacks between human and Earth systems; assess methods of coupling human and Earth system models at a global scale; assess the role of **coupled human and Earth system modeling** within research and in future assessments of climate change.

➤ Large Scale Behavioral Models of Land Use Change

support the creation of the next generation of **large-scale, land-use change models** that take account of human behaviour, agency and decision-making processes

➤ Land Data Assimilation Consortium

form a community of **data assimilation** scientists working with **land surface models** to better quantify and constrain uncertainty in carbon-climate and land-atmosphere feedbacks and promote the use of these methods to the wider modeling community.

➤ *Tipping Elements in the Earth System (in development)*

Climate	Society	Ecosystems	Biogeochemistry